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Climate and Accelerated Erosion in the Arid and Semi-Arid Southwest, With Special Reference to the Polacca Wash Drainage Basin, Arizona

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travelers give of the vegetation depend not only on the particular area observed but on the season and year in which they saw it. Beale's impressions gained in September and February, months following wet seasons of the year (figs. 12, 13, and 26), are in strong contrast to those of Ives, who saw the Navajo-Hopi country in May, one of the two driest months. Vegetation receiving water from melting winter snows or permanent springs, as along the Wepo Wash, would be green in May and June, but vegetation dependent on summer rains of July and August for its growth would not be much in evidence. Colonel Carson's visit in October 1863 and Scott's in November 1891 were at a time of year when the grasses would not have been at their best. Carson's statement that the country around the villages was barren, however, would probably be almost equally true in summer and Scott's description of the Polacca Valley as "almost a desert waste" agrees with Bourke's earlier observations made in August, a month when summer rains are usually plentiful in that region and vegetation should be at the height of its growth.

Similar differences in condition of vegetation arise from the wide yearly variations in climate. However, total annual precipitation and average temperatures are less significant than the distribution of individual rains and droughts (pp. 31–35). That August 1881 must have had rather favorable precipitation is shown by the accounts in Bourke's journal (pp. 113–114). His party was rained on or saw rain near them almost daily for 2 weeks.

The fine plains of choice grama grass described by Bourke are now gone from the Navajo country. Where grama grass is present at all, it grows as scattered individual plants rather than in thick clumps.

LAND USE: PAST AND PRESENT

EARLY RECORDS

Our first knowledge of northeastern Arizona comes from the journals of Coronado's expedition, a party from which explored the area in 1540. At that time the country was inhabited by Pueblo Indians and had not yet been occupied by the Navajos. The Pueblo economy was agricultural, and the Indians had no livestock until sheep and horses were introduced by Coronado.

By the early seventeenth century the Navajos had entered the territory of the Pueblo dwellers, and within the next 100 years had made themselves dreaded enemies of the Pueblo peoples. The warlike invaders attacked the Spaniards and Pueblo dwellers alike, and in these raids obtained the first of the sheep which have since become so important in Navajo life. Amsden (*12, p. 129*) thinks it probable that weaving was established among the Navajos at the time of the Pueblo Rebellion of 1680, when the Spaniards were driven from many of their holdings, particularly in the northern part of what is now New Mexico. In 1692, the Spaniards fought their way back into that area, and permanent settlements were established.

Herding and weaving became more and more important among the Navajos, and according to Amsden (*12, p. 133*) these people had gained a recognized supremacy in native weaving of wool in the Southwest as early as the beginning of the nineteenth century. Until at least the time of the Civil War, the concentration of human and domestic animal population of the Navajo and other tribes of this area of northeastern Arizona was relatively low, and their use of the land could have changed it but little from the natural condition.

The Navajo Reservation was created in 1868, when the tribe was released from Fort Sumner, N. Mex., after the Navajo uprisings had been put down by Kit Carson. It was estimated that 8,000 Indians (*38*) and livestock consisting of 1,550 horses, 20 mules, 940 sheep, and 1,025 goats (*41*) were placed on the reservation at that time. Amsden states (*12, pp. 198–199*) that 30,000 sheep and 2,000 goats were distributed to these Indians in 1869, and 3 years later 10,000 more were brought in. Although these figures are low in comparison to the 48,000 Navajos (*109, table 1*) and 800,000 (*109, table 13*) to more than 1 million sheep and goats [15] reported on the reservation in recent years, it is evident that the period following 1868 marked a great increase in grazing and was the beginning of a critical time in the erosion history of the area.

Additions to the Navajo Reservation changed its boundaries but did not greatly lighten the grazing load.

CHARACTERISTICS AND EFFECTS OF NATIVE LAND USE

Most of the villages of the Hopi Indians in northeastern Arizona long antedate the founding of the Hopi Reservation in 1882, and the agricultural practices of these people have changed but little from contact with the white man. They are essentially tillers of the soil rather than stockmen, and their traditional methods of tillage—hoeing or weeding by hand—the small size and number of their fields, and the location of fields on flat or nearly flat surfaces, have combined to keep to a minimum soil erosion from agricultural causes.

Archaeological evidence indicates that at one time small-house villages, cliff-houses, and pueblos were numerous in the Black Mesa country. Reagan states that they were more closely spaced than farmhouses are in central Iowa today (*84, pp. 144–145*). Each little wash and flat had its village, and water was so carefully gathered and husbanded that none was allowed to escape down the drainageways (*83, p. 340*). Dams and ditches diverted the water of side canyons and made it available for irrigation and village supply. This abstraction of water by man would have the same general effect on valley gradation as would a reduction in rainfall, but without the corresponding general depletion of vegetation. Traces of the dams and other structures can still be found locally (*100, 101*). Whether these works were as numerous at any one time as Reagan suggests is open to question. Most of them have long been in disrepair. If the dams and ditches of these early agriculturists played even a minor part in bringing about aggradation of the valley floors, as a corollary, abandonment and disintegration of the structures, through increase in run-off, might have furthered to a small extent the recent acceleration of erosion.

The Navajos, originally hunters and warriors, are partly nomadic and in general are little inclined to raising cultivated crops. Some have departed from this tradition, however, and the Indian Service

[15] The dipping records of the Bureau of Animal Industry show 1,013,606 sheep units (lambs, rams, goats, and kids) for 1933.

paralleling the prevailing southwest winds (fig. 40). The sand largely covers the pediment slopes of the area, and in places long fingers of sand extend from the valley to the top of the bordering cliffs.

There has been little recent erosion of the lateral slopes in the area up valley from Coyote Springs, in part because of the plant cover and in part because the practice of the Hopi Indians of utilizing for irrigation all flood waters off the slopes above their fields has acted as a check on run-off and has prevented the formation of large lateral gullies. Drainage of the lateral slope zone is obstructed and incomplete, and most of the gullies are small and discontinuous. Small

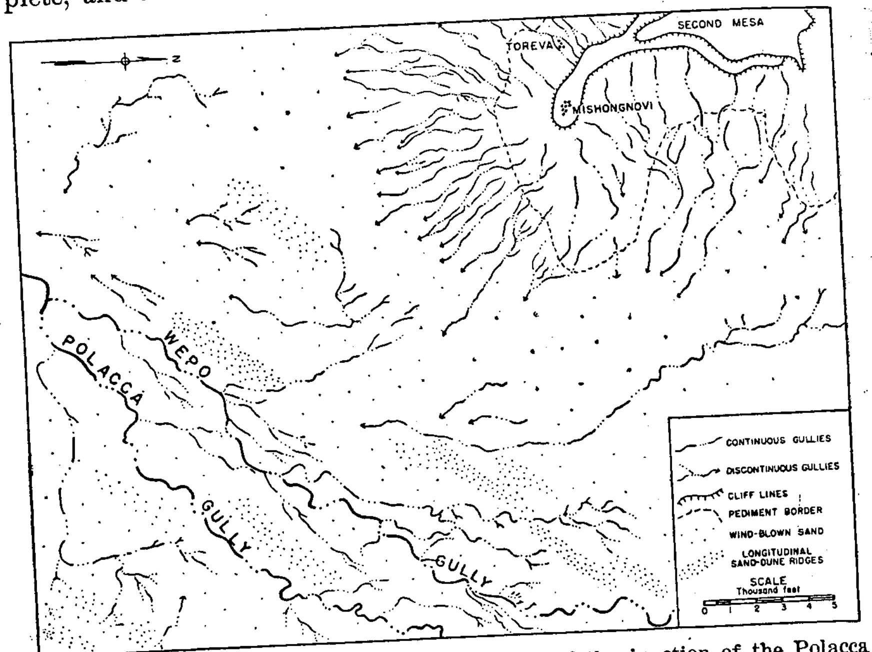

FIGURE 50.—Physiographic map of an area north of the junction of the Polacca and Wepo Gullies, showing the absorption of streams by the broad sand-mantled alluvial surface.

streams survive for short distances, only to be absorbed by the surface sand (figs. 50 and 51). Little of the run-off of the area ever reaches the main Polacca Gully.

The Tolani Lakes area is somewhat warmer and drier than the area above Coyote Springs and is now a broad expanse of sand flats overgrown with brush, willows, and weeds, such as Russian-thistle. Navajo families inhabiting the area have stripped it of much of its natural vegetation. Movement of sand and encroachment of undesirable plant species have resulted.

The condition of the present Polacca Gully in the Tusayan Washes section is somewhat different in the reaches above and below the mouth of the Wepo. Downstream to the mouth of the Wepo the Polacca Gully contains remnants of small terracelike benches, which

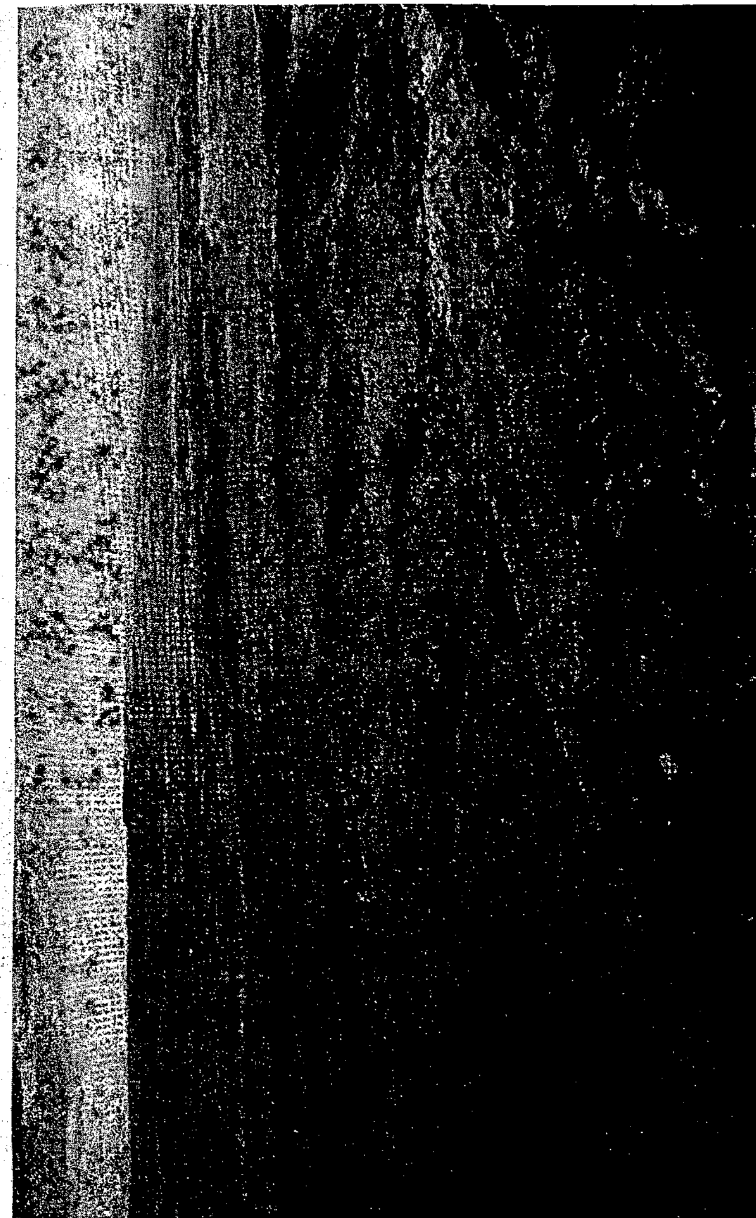

FIGURE 51.—View southwest over the Polacca Wash from First Mesa. Few of the channels on the lateral slope in the foreground reach the Polacca Gully, which is seen winding across the middle of the view.

this channel was in Dripping Springs Canyon (fig. 42), and it may have been a natural feature. These early maps, therefore, suggest that gullying in the Polacca drainage was not well developed until some time after 1883.

According to information obtained from the Hopis, accelerated cutting of the Polacca Wash began in the 1890's at a point several miles below the village of Polacca. The exact location is not known, but field evidence suggests that cutting began about 7 miles down valley from the village (figs. 25 and 26 between *E* and *F*).

On the basis of the positions of longitudinal fans and on comparisons of cross sections of the present gully above and below the fans, the approximate positions of other old gully channels along the course of the present Polacca Gully can be located. One such discontinuous channel is thought to have extended from about a mile southwest of the mouth of Red Canyon (fig. 26 between *A* and *B*) upstream for at least 2 miles; one for a distance of about 3 miles up from the mouth of the Burnt Corn (fig. 26 between *C* and *D*); and one from about 6 miles to 9 miles above the mouth of the Burnt Corn. The longitudinal fans were formed by deposition from discontinuous channels and were later cut through when the channels became incorporated in the continuous gully system.

According to this interpretation, active discontinuous channels were present in four reaches of the main drainage of the Polacca Wash, possibly before the end of the last century. Integration of these channels under the influence of continued accelerated erosion produced the long, continuous Polacca Gully.

Evidence from the major tributaries of the Polacca also indicates that acceleration of erosion began some time after 1890. A land survey made in 1891-92 [19] shows a discontinuous gully in the Wepo Wash, terminating about 5 miles above the present junction of the Wepo with the Polacca—a reach that now contains a continuous gully channel. In Keams Canyon Wash, according to Hoover, writing in 1930 (*62, p. 437*):

> The greatest trenching has taken place within the last 10 or 15 years. Before 1880 there was no serious arroyo wash in Keams Canyon, but later the government experimental farm there was largely washed away and had to be abandoned. The school was moved two miles down the canyon to its present site. The wash is now about 25 feet deep and goes through the middle of the old fields and cemetery.

Gregory, who worked in this area intermittently from 1909 to 1913, said that the deep alluvial fill of Keams Canyon was then being removed so rapidly that location of roads and preservation of buildings was a serious problem (*51, p. 131*).

Cutting of neighboring washes has also taken place largely since 1900. Hoover says of the Oraibi (*62, p. 437*), the next wash west of the Polacca, in 1930:

> The old Oraibi Wash of 30 years ago was no more than five or six feet deep and can still be traced where it was abandoned for the great gash about 35 feet deep and several hundred feet across. Locally it has cut to bed rock, and here there is a constant flow of surface water. It is representative of what has taken place in all the valleys.

[19] U. S. General Land Office. TOWNSHIP NO. 28 NORTH, RANGE NO. 18 EAST, GILA AND SALT RIVER MERIDIAN. Scale, 40 chains to an inch. [Ms. map, United States Department of the Interior.]

Jadito Wash, adjoining the Polacca drainage on the east, has a present channel in some places as much as 100 feet deep. Most of this, according to Hack, has been cut since 1914 (*55, p. 68*).

The weight of evidence indicates that accelerated erosion in the Navajo country began between 1880 and 1885, and gradually spread until by about 1914 all the major drainages and most of the larger tributaries were trenched by a system of continuous gullies. Since then gullies have cut deeper and have joined to form a more complex continuous gully system. Enlargement of channels and extension of the system continues. Parts of some of the larger gullies appear to be less active than they were a few years ago.

Causes of Acceleration of Erosion

DIASTROPHISM

Available information indicates that accelerated erosion in the Southwest was initiated at slightly different times in different areas but that by far the greatest incidence was in the period 1880–1900. In the search for the cause of acceleration of erosion these geologically short time limitations must be kept in mind.

Rejuvenation of stream action would be a possible explanation of the trenching of the valley floors. In individual streams this could be brought about by increase of flow, through capture, or by the cutting through of a resistant barrier such as a massive bed, lava flow, or landslide. More or less synchronous acceleration on streams throughout the Southwest could scarcely result from any such local causes.

A far more widespread cutting of gullies in valley floors could be brought about by steepening of channel gradients through diastrophic action. Any type of doming, warping, or tilting of the earth's crust, however, would involve a directional orientation along which grades would be increased and an orientation in the opposite direction in which grades would be decreased. Warping that would produce increased cutting in southward-flowing streams should produce aggradation in those flowing toward the north in the same area. Vertical uplift or doming would produce a steepening of gradient of streams flowing radially outward from the uplifted area.

No evidence of recent drainage changes of these kinds has been found in the Polacca or elsewhere in the Southwest. Observation of the growth of continuous gullies from short discontinuous ones (p. 92) further suggests that acceleration of erosion has been brought about by changes on and above the earth's surface rather than within the crust.

AGRICULTURE

Where cultivation of the land entails complete removal of natural vegetation and for part of the year leaves the surface entirely bare, the hazard of soil erosion varies with the farm calendar and with the seasonal variations in climate. In the Navajo and Hopi reservations agriculture is well adapted to the climatic conditions and is far less likely to induce serious erosion than are the usual agricultural practices of farmers in somewhat more humid lands.

Few of the Indian fields of northeastern Arizona are ever plowed. Corn, the major crop, is planted in individual holes made with a planting stick. Most of the fields are in sandy areas which retain much of the scant rainfall and therefore do not wash badly. Sand blowing rather than gullying is the major difficulty to be combatted on these fields, and windbreaks of reed, brush, or stones are commonly used. Fields on alluvial fans or on flood plains of arroyos are more subject to gullying. Even here, however, the usual Indian agriculture does little to increase the hazard. Stewart (*100, p. 329*) reports that flood-water irrigation as practiced by the Hopis and the Zunis today is a highly effective means of preventing gullying. The result of land abandonment may be seen on a field that went out of tribal control when boundaries of the Zuni Reservation were realigned about 35 years ago. The flat-bottomed stream which was formerly used to provide floodwater irrigation for the field has now cut a channel approximately 75 feet wide by 20 to 30 feet deep.

Diversion dams and distribution ditches to irrigate the fields are reported to have been very numerous in the past (*82*, *100*), and if properly maintained must have acted to prevent rather than induce accelerated erosion. Abandonment of these works, as Reagan (*82*) has suggested, may have been a contributing factor in starting accelerated channel cutting. Bryan [20] believes there were fewer dams than Reagan indicates and that their effect on alluviation and erosion was small. It seems certain, however, that in the areas most intensively cultivated the water-control structures of these early farmers were highly effective in retarding run-off and in causing alluviation.

Little is known of the number of inhabitants in northeastern Arizona before the coming of the Spaniards. Espejo in 1583 estimated the number of the Moquis at 50,000, but this is thought to have been far too high (*43, p. 15; 48, p. 661*). In 1776 the engineer Miguel Costanso [21] made an estimate of 7,494 (*43, p. 15*). This figure, which is also given by Escalante, agrees well with other estimates of that period. In 1780, however, after 3 years without rain, Governor Anza gave the population as 798 and the deaths as 6,698. Whipple in 1853 noted the population as 6,720 (*111, p. 13*), the Eleventh Census in 1890 as 1,996 (*43, p. 49*), and the Indian Service in 1939 as 3,339, including 114 Hopis residing off of the reservation (*109, table 3*).

Considering that the Hopi population probably has never exceeded 8,000 and that the Navajos have gradually risen to their present 48,235 (*109, table 2*) from a start of about 8,000 in 1868, it is improbable that the Indian lands have ever been much more intensively farmed than they are today.

In recent years only about 38,000 acres on the Navajo and Hopi reservations have been under cultivation, exclusive of a small area around Gallup, N. Mex., and of acreage operated by the Indian Service. The cultivated acreage, less than 60 square miles, is approximately 0.25 percent of the two reservations excluding the Gallup area, or an average of 1.6 cultivated acres per square mile.[22] The proportion in the Hopi country is higher, 7.6 acres per square mile in 1936, but above and below the Hopi lands on the Polacca and adjoining drainage basins cultivated land falls to less than the average for the reservations. Considering the small amount of land cultivated it seems impossible that agriculture could have been a significant cause of the acceleration of erosion.

[20] See footnote 18, p. 102.

[21] CONSTANSO, MIGUEL. DICTAMEN . . . SOBRE DISTANCIAS DEL NUEVO MEXICO A SONORA, Y A MONTERREY. [Ms.] Arch. Gen. y Pub. de la Nac., Prov. Int., v. 169, item 2. Mar. 18, 1776. Mexico City.

[22] U. S. SOIL CONSERVATION SERVICE. STATISTICAL SUMMARY HUMAN DEPENDENCY SURVEY, NAVAJO AND HOPI RESERVATIONS. 41 tables and map. Albuquerque, N. Mex. Rev. 1939. [Mimeographed.] (See tables 1 and 24.)

CLIMATE

Many of those who have considered the acceleration of erosion in the Southwest have concluded that it has been brought on by a change of climate. The exact mechanism operative or the amount of change necessary to produce the accelerated cutting are not stated, but references to progressive desiccation, decreased rainfall, or greater relative aridity are common. Huntington (*65*, *66*, *67*), Gregory (*51*), Visher (*110*), and Bryan (*23*, *28*) have suggested such a change as the cause of recent channel trenching (pp. 45–46).

RELATION OF CLIMATE TO NORMAL AND ACCELERATED EROSION

The possible effects of change of climate on rate of erosion are many and varied. Increase or decrease of precipitation are the changes most prone to affect run-off and are therefore of greatest significance in the problem.

Decrease of precipitation in an arid or semiarid land reduces the vigor of plant growth. The less hardy specimens die, the survivors are reduced in size or strength, and there is a general shift toward a more xerophytic vegetation. With decreasing precipitation there is also less water to flow off the lands. Three results are possible: (1) If the effect of vegetal depletion is less than that of reduction in precipitation, run-off will be less destructive and the hypothetical change of climate will bring less erosion than formerly; (2) vegetal depletion may balance decrease in precipitation and erosion conditions may remain the same as before; (3) depletion of vegetation may be more effective than the decrease in precipitation and, particularly if individual storm intensity remains the same, run-off and erosion will be accelerated.

Moderate increase of precipitation may have the opposite of any of these three effects. In an arid or semiarid land moderate increase should improve the vegetal cover on slopes. A great increase in precipitation is likely to cause degrading of stream valleys temporarily, until vegetal protection can adjust fully to the new climatic conditions. There is a question, then, in any area whether increase or decrease of annual precipitation would be most likely to cause acceleration of erosion. It has been assumed by most of the proponents of the climatic-change hypothesis, that a decrease in precipitation, by lowering the resistance offered by vegetation to run-off has brought about the increase in erosive activity in the Southwest. Huntington (*66, p. 32*) stresses the complimentary process. He points out that depletion of vegetation because of decreased precipitation so increases the amount of debris removed from the slopes that streams are overloaded and must aggrade rather than degrade their valleys. It must be kept in mind that processes are different in upstream and downstream parts of the same drainageway. In arid drainages that do stantly becoming larger by reason of the heavy rains in July and August of each year.[27] The report for the same agency in 1913 shows a picture of the arroyo in Keams Canyon "within one mile of its beginning, where the canyon is narrow. Depth approximately fifty feet." The caption notes further that 10 years before there had been no evidence of such an arroyo.[28]

The annual report [29] for the next year states that the first days of July were rainy and that on Sunday, July 5, 1914 0.7 inch of water fell in 15 minutes. Great damage resulted. Rains between August 26 and September 3, 1915, in the vicinity of Keams Canyon destroyed roads and rendered communication exceedingly difficult.

In 1919 the Superintendent [30] of the Moqui Agency reported: "On July 15th, 1919, in Keams Canyon, one inch of rain fell in thirty minutes. This was a flood that caused one to wish he had an Ark."

Only 2 years later, on August 4, a cloudburst washed out the retaining walls at the Keams Canyon agency and destroyed roads, crossings, and bridges, cutting off all communication with the schools.[31]

It is apparent from the foregoing descriptions and from that by Hoover (p. 106) that the major gullying in Keams Canyon probably started between 1903 and 1911 but that the gully did not approach its present size until about 1915 or 1920. The part played by the occasional intense rains in the cutting of this gullied channel is clearly indicated by the above accounts.

Intense rains have caused accelerated cutting and serious property damage in many other parts of the Navajo country. A cloudburst on the evening of July 24, 1921, near Fort Defiance Agency rushed down Bonito Creek 10 feet deep destroying protective works that had stood for 16 years. A road and 200 feet of pipe line were washed away, cutting off the water supply. Damage was estimated at $10,000 to $12,500.[32] [33]

Superintendent Kneale [34] of the San Juan Agency at Shiprock, N. Mex., reported on September 19, 1925:

I have to report a cloud burst yesterday P.M., about 3:00, lasting practically one half hour. The water flowed over the highway near the athletic field to a depth of three feet; the ware house, jail, and all cottages were surrounded by water to a depth of one feet or more; water flowed down the highway leading toward Farmington to a depth of one foot. Some of our crops are buried under many inches of ooze and some are washed away; fences were destroyed; ditches filled and obliterated; bridges and roads washed out; the basement at the Mesa School was partially filled with mud and water. However there was no accident or loss of life.

There have been numerous such storms, during the past six weeks, on all sides of us, keeping the arroyas full and the roads for the most part impassable, but this one hit Shiprock squarely.

[27] LAWSHE, A. L. ANNUAL REPORT FOR THE FISCAL YEAR, 1911, OF THE MOQUI INDIAN SCHOOL, ARIZONA. [Ms., Nat. Arch.]
[28] CRANE, LEO. ANNUAL REPORT OF THE SUPERINTENDENT, MOQUI INDIAN RESERVATION, ARIZONA [FOR 1913]. PICTORIAL SECTION. [Ms., Nat. Arch.]
[29] CRANE, LEO. ANNUAL REPORT OF THE SUPERINTENDENT, MOQUI INDIAN RESERVATION, ARIZONA [FOR 1914]. NARRATIVE SECTION. [Ms., Nat. Arch.]
[30] CRANE, LEO. EIGHTH ANNUAL REPORT [1919] OF THE SUPERINTENDENT FOR THE MOQUI INDIAN RESERVATION KEAMS CANYON, ARIZONA. NARRATIVE SECTION. [Ms., Nat. Arch.]
[31] DANIEL, [R. E.] Telegram to the Indian Office, Washington, D. C., from Moqui Agency, Keams Canyon, Aug. 4, 1921. [Ms., Nat. Arch.]
[32] PAQUETTE, [PETER]. Telegram to the Indian Office, Washington, D. C., from Fort Defiance, Ariz., July 25, 1921. [Ms., Nat. Arch.]
[33] ——— Letter to Commissioner of Indian Affairs, Washington, D. C., from Fort Defiance, Ariz., July 26, 1921. [Ms., Nat. Arch.]
[34] KNEALE, A. H. Letter to Commissioner of Indian Affairs, Washington, D. C., from the San Juan Agency, Shiprock, N. Mex., Sept. 19, 1925. [Ms., Nat. Arch.]

If records of heavy rains and resulting erosion damage in the Navajo country were more complete, a much more detailed picture should be available of the close relation between storms and erosion suggested by these scattered accounts of the cutting of Keams Canyon Gully and the damaging erosion near Fort Defiance and at Shiprock Agency.

As there is no indication that there has been either an increase or a decrease in the average annual amounts of precipitation in the past 2,000 years or that heavy storms are now any more frequent or more severe than they have been in the past (pp. 43–46), the explanation of the increased erosion by run-off and the heightened floods must be sought outside of the field of meteorology.

GRAZING

Evaluation of the role of overgrazing in bringing about accelerated erosion in the Southwest can be based in part on correlation of the time of starting of heavy grazing and the date of gully cutting in various valleys. As the Southwest developed primarily as a cattle country, it is only natural that the introduction of large herds took place as early as or earlier than the establishment of permanent white settlements. Herds grew in size rapidly, and the grazing load increased until in many areas it soon exceeded the safe range capacity. In humid years when the vegetal cover was at its best the large load could be carried. With the coming of a dry year or a succession of dry years, however, the cover was far from sufficient for the livestock. It was inadequate also to protect the land from erosion.

The facts are clear that acceleration of erosion followed close on the heels of the introduction of heavy grazing. Considering the large number of valleys throughout the Southwest where this is found to be true, the relation can hardly be fortuitous.

Rillito Creek, near Tucson, began cutting after the opening of the Army post at Fort Lowell in 1872. According to Smith (*96, p. 98*) the valley was first settled in 1858, and at that time was an unbroken forest, principally of mesquite, with a good stand of grama grass and other grasses between the trees. When the Army post was opened hay was needed in large quantities. A few years of cutting hay killed much of the grass, and cattle introduced during the seventies further destroyed the forage and developed trails, which soon eroded to gullies.

According to a rancher (*53, p. 12*), the San Pedro Valley, Ariz., had a luxuriant growth of vegetation in 1870. He continues:

There were fully 50,000 head of stock at the head of Sulphur Spring Valley and the valley of the Aravipa in 1890. In 1900 there were not more than one-half that number and they were doing poorly.

Another rancher (*53, pp. 13–14*) on the San Pedro said in 1900:

Of the rich grama grasses that originally covered the country so little now remains that no account can be taken of them.

* * * * * * *

Twelve years ago 40,000 cattle grew fat along a certain portion of the San Pedro Valley where now 3,000 can not find sufficient forage for proper growth and development. If instead of 40,000 head 10,000 had been kept on this range, it would in all probability be furnishing good pasture for the same number to-day. Very few of these cattle were sold or removed from the